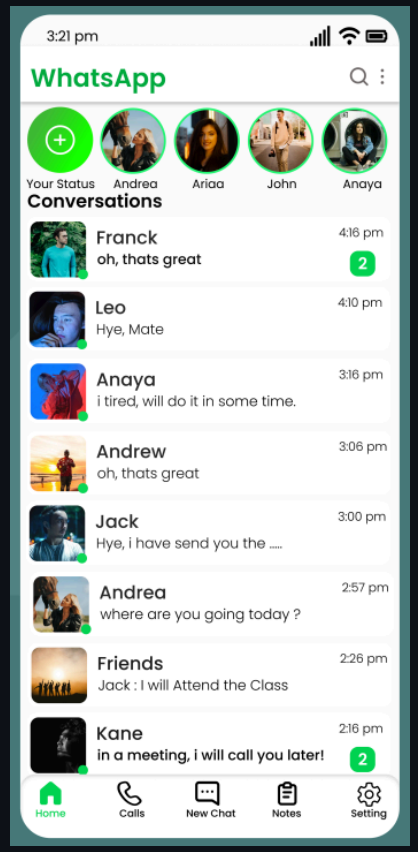
Incremental View Maintenance (IVM)

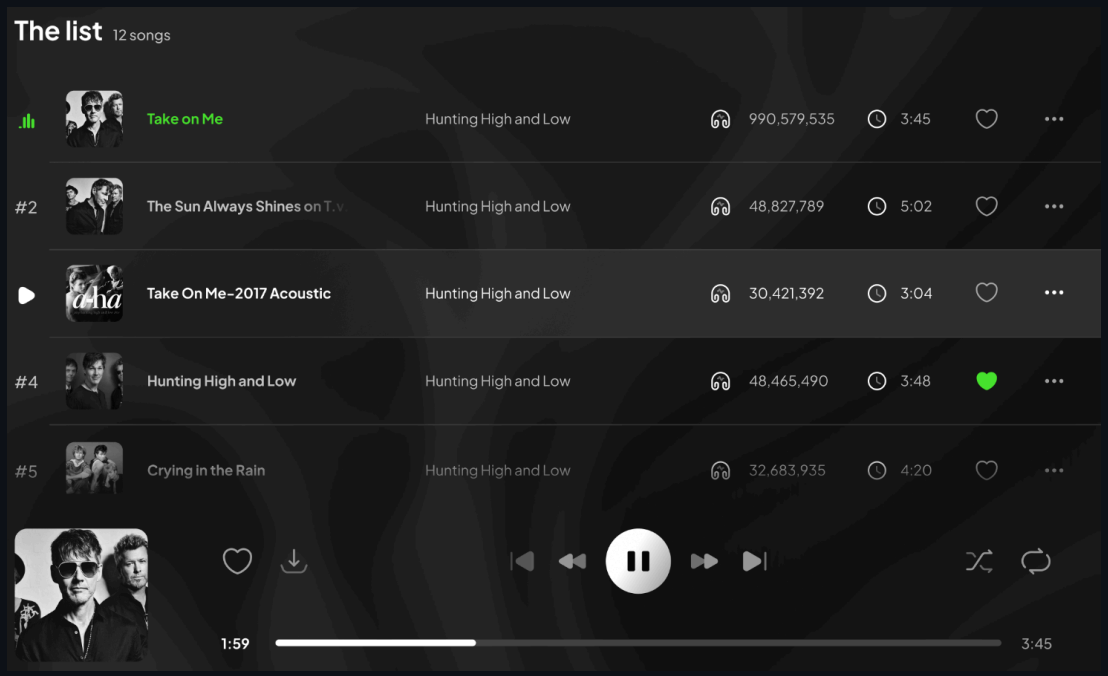
06/23/2024 - Matt Wonlaw, Rocicorp

Why talk about IVM @ a Local-First event?

Apps are views over data




```sql
SELECT
  thread.name,
  (SELECT array(name) FROM user WHERE user.id IN thread.participants)
  as participants,
  (SELECT object(name, date) FROM message
    WHERE message.threadId = thread.id LIMIT 1)
  as lastMessage
FROM thread;
```




```sql
SELECT
  track.*,
  (SELECT array(artist.name) FROM artist
    JOIN trackArtist WHERE trackArtist.trackId = track.id)
FROM playlist
  JOIN trackPlaylist
  JOIN track
```

As the state in the database changes, views should automatically update.

re-running every query on state change is too expensive.

Introducing IVM

- Think of it as:
  - A data dependency graph (like signals) plus
  - Incremental computation over collections
- E.g., `map` / `reduce` / `filter` but without making copies and by only running compute over modified items

Without IVM

```
x.map(..).filter(..).reduce(..);
```

Any modification to `x` results in `N` array copies.

Without IVM

```
const issues = Array.from({length: 100_000}, genIssues);
const fooIssues = issues.filter((issue) => /.*foo.*/.test(issue.title));
```

Any modification of `issues` re-scans `100_000` items

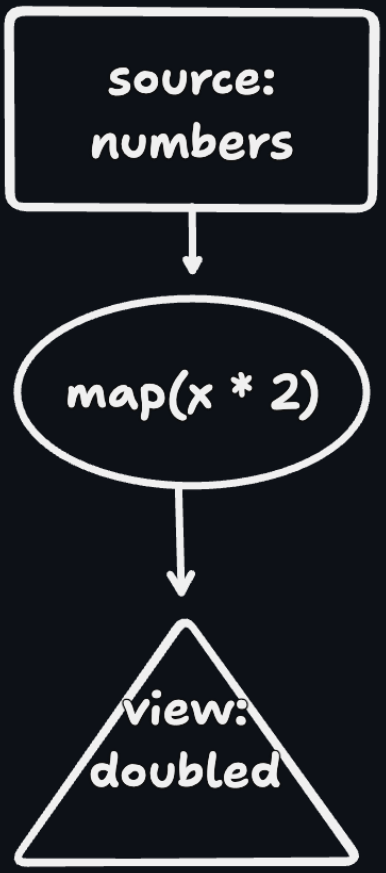
Implementing IVM

Terminology

- **Pipeline** - a chain of computations.
  E.g., `x.map.filter.reduce`
- **Source** - the data provider and root of the pipeline.
  E.g., the `x` in `x.map.filter.reduce`
- **Operator** - an internal node in a pipeline.
  E.g., `map` / `filter` / `reduce` / `join`
- **View** - the final result of a pipeline.
  E.g., `const view = x.map.filter.reduce`
- **Difference** - a change sent through the pipeline

Simple Pipeline

```
doubled = numbers.map(x => x*2)
```



Incremental `map`

```
numbers.map(x => x*2)
```

- Map already is incremental
- Only depends on a single, not the entire collection
- The problem is preserving a relationship between `source` and `view`

Incremental `map`

```
numbers.map(x => x*2)
```

Preserving View & Source Relationship

- A modification of an input in the source should modify the corresponding output
- Options:
    i. Make the `source` and `view` each a `Map<K, V>` to associate items with a key
    ii. Make the `source` and `view` take a `comparator<S, V>`
- Option (1): Diff events take the form of `[key, value]`
- Option (2): Diff events are still just the `value`

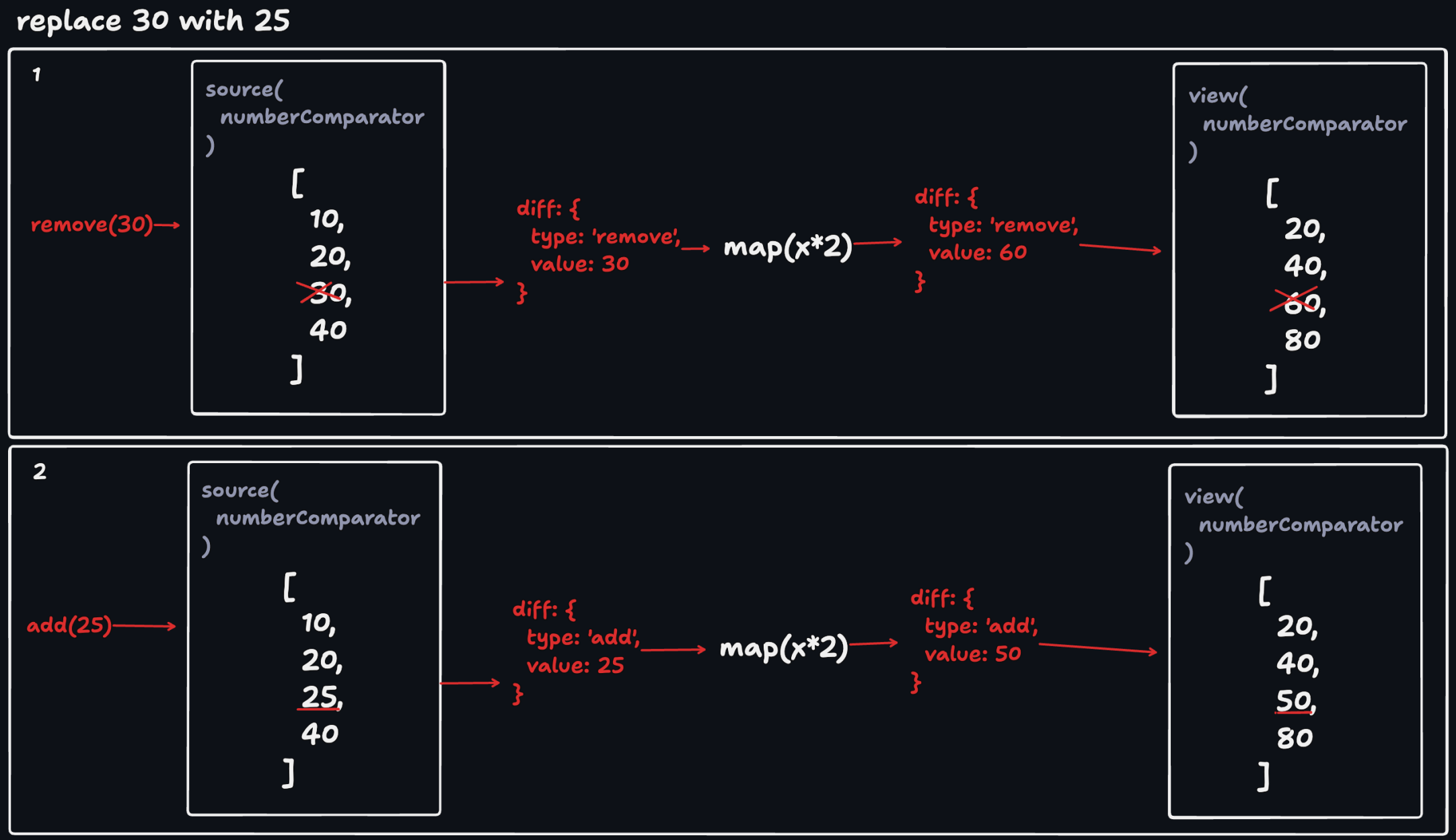
Tracking Deletes, Updates, Adds

- Add an event `type` to the difference event

```
type DifferenceEvent<T> = {
  type: 'add' | 'remove',
  value: T
};
```

- `update` is modeled as `remove` followed by `add`

Putting it together



Notes:

1. `filter` can be implemented similarly
2. `join` and `reduce` operators need to consider past values. Require "memory" to make them incremental.
3. Duplicate entries in a collection can be handled by adding a multiplicity to difference events.

```
type DifferenceEvent<T> = {
  multiplicity: number; // -N: remove N times. +N: add N times. 0: no-op.
  value: T;
};
```

An incremental query language with incremental `map/reduce/filter/join`?

Example: Modeling SQL

SELECT = `map`

```
// SELECT title FROM issue
issues.map(i => i.title)
```

WHERE = `filter`

```
// SELECT * FROM issue WHERE priority = 1
issues.filter(i => i.priority = 1)
```

WHERE .. AND .. = `filter.filter`

```
// SELECT * FROM issue WHERE priority = 1 AND status = 1
issues.filter(i => i.priority = 1).filter(i => i.status = 1)
```

Example: Modeling SQL

WHERE .. OR .. = `x.filter.concat(x.filter).distinct`

```
// SELECT * FROM issue WHERE priority = 1 OR status = 1
issues.filter(i => i.priority = 1).concat(issues.filter(i => i.status = 1)).distinct(i => i.id)
```

GROUP BY (or any aggregation) = `reduce`

```
// SELECT * FROM issue GROUP BY status
issues.reduce((acc, issue) => {
  const existing = acc.get(issue.status);
  if (existing) {
    existing.push(issue);
  } else {
    acc.set(issues.status, [issue]);
  }
}, new Map())
```

Example: Modeling SQL

JOIN = `join`

Custom operator that correlates two streams. Conceptually:

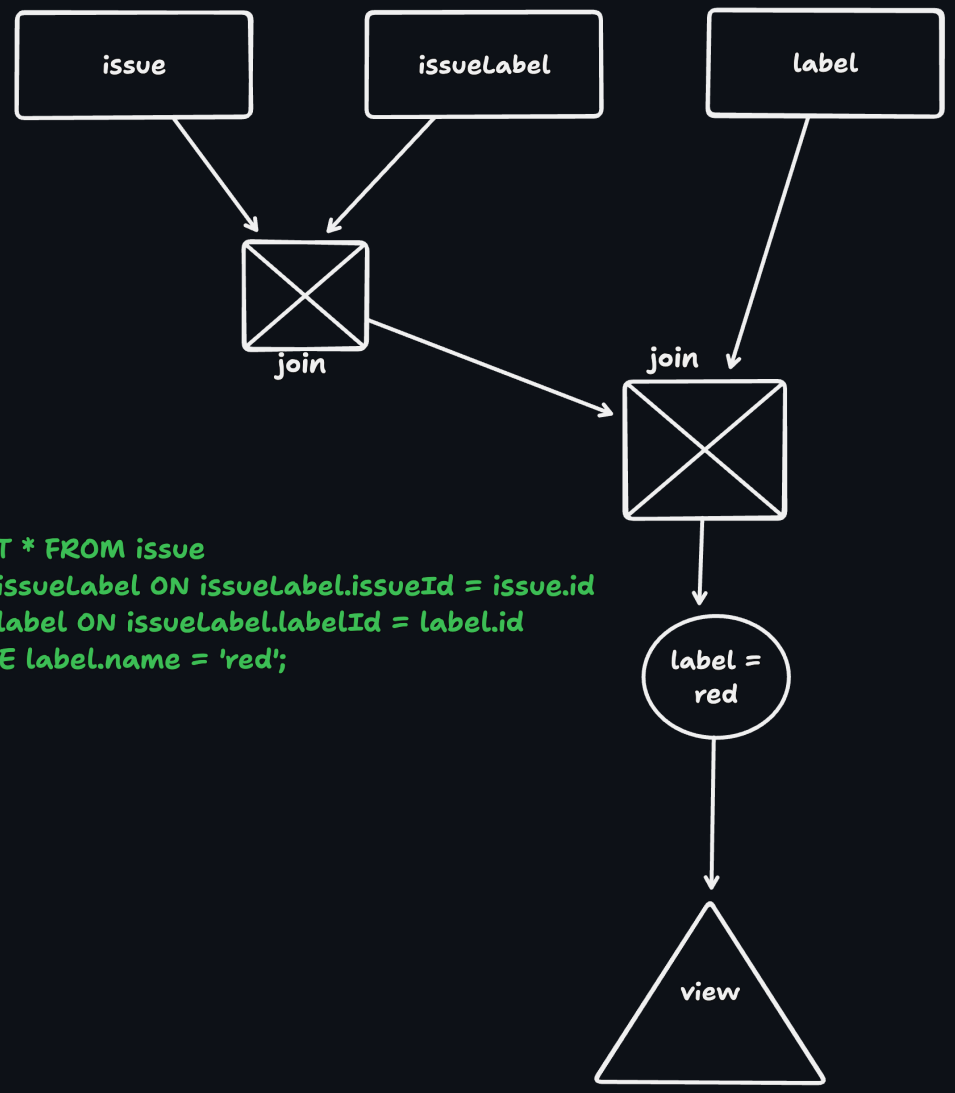
```
// SELECT * FROM issue JOIN user ON issue.owner_id = user.id
issues.map(issue => {
  const user = users.get(issue.owner_id);
  if (user) {
    return {
      issue,
      user
    };
  }
  return undefined;
}).filter(row => row !== undefined)
```

But updated to handle `difference events`, be incremental and respond to changes in either the `user` or `issue` table.

Modeling SQL

1. Map each language construct to an incremental `filter` / `map` / `reduce` / `join` / `concat` / `distinct` operator
2. Wire these operators together in a DAG

Example DAGs

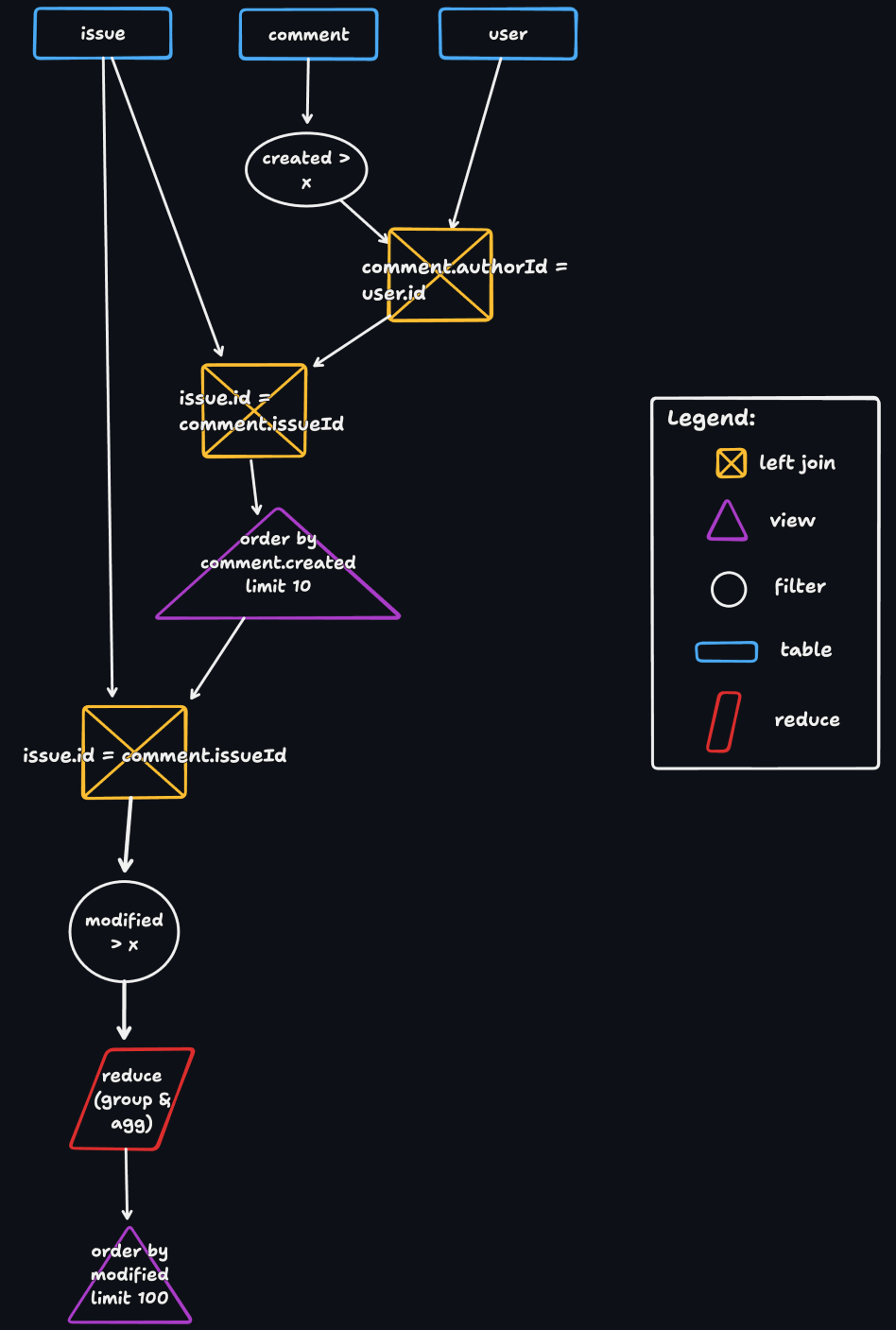



```
SELECT * FROM issue
JOIN issuelabel ON issuelabel.issueId = issue.id
JOIN label ON issuelabel.labelId = label.id
WHERE label.name = 'red';
```

```sql
SELECT
  title,
  (SELECT
    json_group_array(json_object(
      'body', body,
      'author', (SELECT
        json_group_array(name)
        FROM user WHERE user.id = comment.authorId
      )
    )) FROM comment
    WHERE created > x AND comment.issueId = issue.id
    ORDER BY created ASC LIMIT 10
   ) AS comments
FROM issue WHERE modified > x ORDER BY modified DESC LIMIT 100
```

I.e.,

```ts
issue.select(
  'title',
  iq => iq.related('comments')
    .where('created', '>', date)
    .select(
      'body',
      cq => cq.related('author').select('name')
    )
    .order('created').limit(10),
).order('modified', 'desc').limit(100);
```



Demo

- Linearite 1 mil
- ZQL vs SQLite

Further Topics

- Subqueries
- Recursive queries
- Normalizing queries
- Sharing structure between pipelines for efficiency
- First run & query planning
- Reducing memory consumption of `join` & `reduce`
- Re-ordering the DAG
- Index creation
- Order By & Limit: properties of the `view`

Resources

- Incremental Query Language Theory: https://github.com/vmware-archive/database-stream-processor/blob/main/doc/vldb23/main.pdf
- Signals: http://adapton.org/
- In our new product as "ZQL (Zero Query Language)" https://zerosync.dev/